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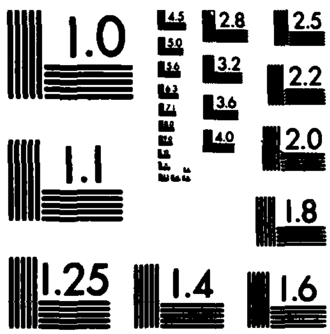
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# AUDITORY INDUCTION OF DISCRETE TONES IN SIGNAL DETECTION TASKS

Kevin B. Bennett, Raja Parasuraman, James H. Howard, Jr., and Alice J. O'Toole

ONR CONTRACT NUMBER N00014-79-C-0550

Technical Report ONR-83-23

Human Performance Laboratory

The Catholic University of America

October, 1983

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

| REPORT DOCUMENTATION PAGE | | READ INSTRUCTIONS BEFORE COMPLETING FORM |
|---|---|---|
| 1. REPORT NUMBER<br>ONR-83-23 | 2. GOVT ACCESSION NO. | 3. RECIPIENT'S CATALOG NUMBER |
| 4. TITLE (and Subtitle)<br>Auditory Induction of Discrete Tones in Signal Detection Tasks | | 5. TYPE OF REPORT & PERIOD COVERED<br>Technical Report |
| | | 6. PERFORMING ORG. REPORT NUMBER |
| 7. AUTHOR(s)<br>Kevin B. Bennett, Raja Parasuraman, James H. Howard, Jr., and Alice J. O'Toole | | 8. CONTRACT OR GRANT NUMBER(s)<br>N00014-79-C-0550 |
| 9. PERFORMING ORGANIZATION NAME AND ADDRESS<br>The Catholic University of America<br>Washington, D.C. 20064 | | 10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS<br>61153N 42; RR 042 09; RR 042 09 01; NR 196-159 |
| 11. CONTROLLING OFFICE NAME AND ADDRESS<br>Engineering Psychology Programs, Code 442<br>Office of Naval Research<br>Arlington, VA 22217 | | 12. REPORT DATE<br>14 October, 1983 |
| | | 13. NUMBER OF PAGES<br>33 |
| 14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) | | 15. SECURITY CLASS. (of this report)<br>Unclassified |
| | | 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE |

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

auditory continuity
auditory illusion
auditory induction
passive sonar
signal detection
top-down processing

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Auditory induction is the apparent continuation of a fainter sound when alternated rapidly with a more intense interrupting sound. In the present study induction of discrete (non-alternating) tones by "contextual" tones was examined in three experiments using signal detection methods. Listeners were asked to detect pure tone signals of constant, rising, or falling frequency embedded in noise bursts. The noise bursts were preceded --

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S/N 0102-LF-014-6601

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and followed by contextual tones that were designed to produce a constant or changing frequency context. The results of the first two experiments showed that detection of "in-context" signals (e.g., a rising frequency signal in a rising frequency context) was associated with an increased false-alarm rate and lowered sensitivity compared to "out-of-context" signals (e.g., a falling frequency signal in a rising frequency context). To examine the possible influence of peripheral masking a third experiment was conducted in which signals and contextual tones were presented to different ears. The same pattern of selective contextual impairment of detection performance was obtained. The results indicated that auditory induction can occur with discrete presentation of tones: the contextual tones are perceived as continuing through the noise bursts and this illusion degrades detection performance. However, the effect occurs only when a signal to be detected is consistent with its context. The results also suggest that auditory induction and masking are independent processes that can cumulatively degrade detection performance with nonspeech sounds.

# Auditory Induction of Discrete Tones in Signal Detection Tasks

Perception of speech and of other environmental sounds can reflect the influence of either bottom-up (sensory) or top-down (cognitive) factors. Bottom-up factors such as the acoustic waveform and peripheral auditory mechanisms determine the initial input while top-down factors related to a listener's skills, intentions, and knowledge act upon this input to construct a perceptual representation. Since auditory perception usually reflects the joint or interactive influence of both bottom-up and top-down factors (e.g., Samuel, 1981a) a strict division of factors affecting perception into bottom-up and top-down cannot always be made.

One important top-down factor influencing auditory perception is attentional focusing (Swets, in press), which allows a listener to direct limited-capacity attentional resources to important aspects of the auditory input. For example, temporal structure can facilitate attentional focusing on specific elements of a pattern (Watson & Kelly, 1981). Listeners can also use their knowledge of structural constraints to improve their ability to detect missing pattern elements in complex auditory patterns (Howard, O'Toole, Parasuraman, & Bennett, Note 1). As a listener gains familiarity with sound patterns, attentional focusing allows particularly salient aspects of the pattern to be perceived with greater clarity.

Another top-down factor in perception is "auditory induction," which is the general term for an auditory illusion in which sounds not actually in the waveform are perceived as being present given a certain "context" (Warren, Obusek, & Ackroff, 1972). In speech research the phenomenon is referred to as

"phonemic restoration" (e.g., Warren, 1970; Samuel, 1981a, 1981b). In research on the perception of nonspeech sounds, the effect has alternately been referred to as the "picket fence" effect (Miller & Licklider, 1950), an auditory "figure-ground" effect (Thurlow, 1957), "auditory continuity" (Thurlow & Elfner, 1959), and the "pulsation threshold" (Houtgast, 1972).

Auditory induction has been shown to occur when sounds are alternated: one sound is perceived as continuously present (the induced sound) while the other sound (the inducing sound) is perceived as intermittent, or pulsing. Certain conditions, which roughly coincide with the conditions necessary for masking (Warren et al., 1972), must be met for the effect to occur. In general, when a sound of long duration and low intensity (the induced sound) is interrupted with a sound of shorter duration and higher intensity (the inducing sound) the fainter sound is perceived as continuous. The effect is diluted or absent when silence is inserted between the sounds. Auditory induction has been shown to occur with two alternating tones of similar frequency (Dannenbring & Bregman, 1976; Elfner, 1971; Houtgast, 1972; Thurlow & Elfner, 1959; Warren et al., 1972), with three alternating tones differing only in intensity (Warren, et al., 1972), with noise as the induced sound and a tone as the inducing sound (Elfner & Caskey, 1965; Elfner, 1969; Elfner & Homick, 1966; Elfner & Marsella, 1966), with a tone as the induced sound and noise as the inducing sound (Warren, et al., 1972; Dannenbring, 1976), and with alternating noise bursts (Thurlow & Marten, 1962; Dannenbring & Bregman, 1976).

Top-down processes are extremely useful in the perception of complex acoustic patterns. Attentional focusing allows selected portions of these patterns to be perceived with greater clarity (Howard et al., Note 1); auditory induction allows portions of the acoustic waveform that are missing or masked to

be reinstated. Samuel (1981a, 1981b) has shown that speech perception under noisy or degraded conditions may be enhanced considerably by auditory induction. However, while auditory induction may benefit perception of speech, it may hinder performance of nonspeech perceptual tasks. In certain monitoring situations (e.g. passive sonar), auditory induction may degrade performance if sounds not present in the auditory input are induced, thus causing false target reports.

Previous research has examined auditory induction only in the context of rapid and continuously alternating sounds. For example, Warren et al. (1972) asked listeners to adjust the intensity of to-be-induced tones that were alternated with a 1000 Hz inducing tone. The intensity required to make the tone sound just continiuous was used as an estimate of auditory induction. These results cannot be easily generalized since rapid alternation has been shown to distort the perception of stimuli. Bregman (1978), for example, has shown that tones of sufficient frequency separation form "streams" or "channels" which are perceived as simultaneous and independent, rather than as temporally alternating. The present study investigated auditory induction in a more generalized task situation (non-alternating, or discrete sounds) that allows the use of a signal detection paradigm to measure induction effects on perceptual performance.

Three experiments were carried out using pure tone signals embedded in band-limited noise. The signals were of three types, constant, rising, or falling in frequency, and were presented over a 200 ms observation period. The first experiment examined whether auditory induction of a constant frequency tone could occur with non-alternating (discrete) presentation. It was hypothesized that induction would degrade performance for the constant signal

but not the rising or falling signals. The second experiment examined whether similar effects on performance could be obtained for signals of changing frequency (the rising and falling signals). In the third experiment the inducing and to-be-induced sounds were presented to different ears to investigate the role of peripheral and central masking mechanisms in auditory induction.

## Experiment 1

A modified version of a yes-no signal detection task was used in the first experiment. Signals were of three types, rising, falling, or constant in frequency, and were embedded in a 200 ms burst of band-limited noise. Listeners were tested under two conditions. The no-context or non-induction condition was similar to a standard yes-no detection task. In this condition listeners had to detect signals in a 200 ms observation period containing either noise alone (N) or signal plus noise (SN). In the context or induction condition, the 200 ms observation period was preceded and then followed by a "contextual" tone, constant in frequency and 800 ms in duration. The durations and intensities of the preceding and following contextual tones and the noise burst were chosen so that auditory induction would be likely to occur (Dannenbring, 1976). Figure 1 shows the composite structure of the stimuli in the context and no-context conditions.

If auditory induction occurs, the preceding tone would be perceived as continuing through the noise burst and extending to the following tone. Therefore, it was hypothesized that the context condition would produce a higher false-alarm rate than the no-context condition. It was also hypothesized that in the context condition listeners would be able to detect the rising and falling signals but would show a degraded ability to detect the constant tone

because of auditory induction, whereas all three signals would be equally detectable in the no-context condition.

Insert Fig. 1 about here

## Method

Participants. Nine paid listeners aged 20-26 served as listeners in the experiment. The listeners were recruited from a pool and two had previous experience in psychoacoustic experiments. None reported a history of hearing disorder. However, one listener was dropped because of an inability to detect signals at above-chance levels.

Stimuli. All stimuli were synthesized on a digital computer using standard algorithms. The 800 ms contextual tone (with 5 ms rise and fall times) that preceded and then followed the 200 ms bursts was 1000 Hz in frequency (the same as the constant signal) and was presented at an intensity of 77.8 dB SPL. Each of the 200 ms bursts contained noise (band-pass filtered between 500 and 1500 Hz, -3 dB points), and were presented at an intensity of 81.2 dB SPL. In the SN bursts 200 ms pure tones were added to the noise. The constant signal was a pure tone with a frequency of 1000 Hz. The rising signal was a pure tone with a starting frequency of 800 Hz that rose linearly to 1200 Hz by the end of the 200 ms period. The falling tone was a pure tone that had a starting frequency of 1200 Hz that fell linearly to 800 Hz. The signals were presented at a signal-to-noise ratio (E/No) of 19. (Values of E/No were adjusted using the equation given by Green, McKey, and Licklider, 1959).

Apparatus. All experimental events were controlled by a general purpose

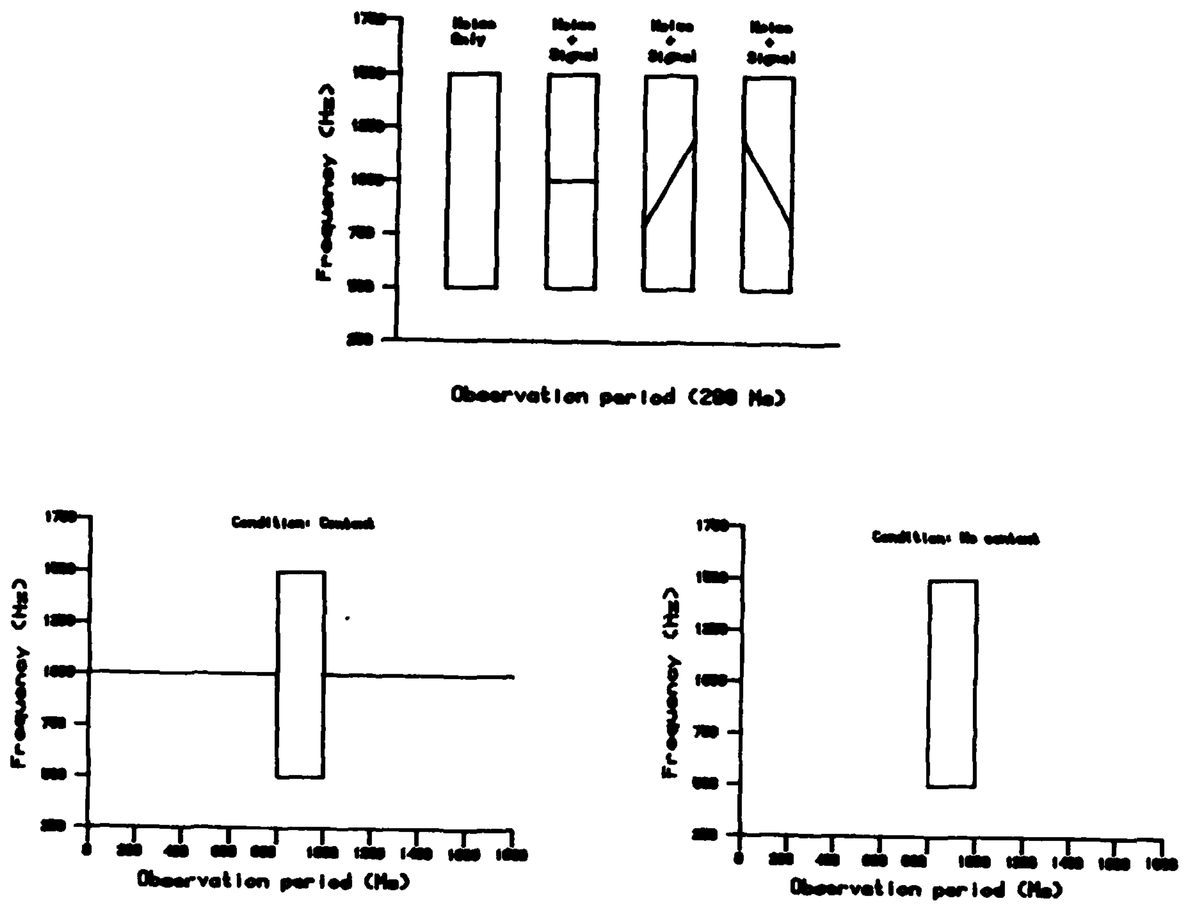


Figure 1. Composite structure of the stimuli in the yes–no detection task of Experiment 1. In the no-context condition (lower right) a 200 ms observation window containing either noise alone (bandwidth 500 - 1500 Hz) or noise plus signal was presented. In the context condition (lower left), the noise burst was preceded and followed by a constant frequency (1000 Hz) contextual tone. Signals could be of three types: constant, rising, or falling in frequency (see upper half).

laboratory computer (Digital PDP-11/23). The tones were output on a 12 bit digital-to-analog converter (Data Translation, model DT-2771) at a sampling rate of 5 kHz, attenuated (Texscan, model SA-50), low-pass filtered (Krohn-Hite, model 3750) at 2.5 khz, and presented binaurally over calibrated, matched headphones (Grason-Stadler, model TDH 39-10Z). Listeners were seated in an Industrial Acoustics soundproof booth (model 1602A) and a Zenith video terminal (model WH19) was used to present experimental prompts and record listener responses.

Procedure. Listeners were tested individually in two 1.5 hour sessions held on consecutive days. One practice block and four experimental blocks were given on each day. The practice block consisted of 72 trials; each experimental block consisted of 144 trials. Rest breaks were provided between blocks. The order of conditions (context condition on the first day and no-context condition on the second day) was reversed for successive listeners.

In the practice block the initial signal-to-noise ratio (E/No=23) was chosen so that signals were relatively easy to detect. Following several practice trials at this level, the signal-to-noise ratio was reduced to E/No=21, and finally to the level used in the experimental blocks, E/No=19. The context and no-context conditions were presented in different experimental blocks. Within each experimental block, N and SN trials were presented an equal number of times. On any SN trial, the constant, rising, or falling signal could occur with equal a priori probability, and feedback was given. A total of 1152 trials was presented to each listener.

## Results

The proportion of false alarms, P(FA), and of correct signal detections (Hits), P(H), for each of the three signal types, were obtained for each listener in both the context and the no-context conditions. A *t* test was used to compare P(FA) in the context and no-context conditions. A two (context condition) by three (signal type) analysis of variance was performed on the P(H) data.

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Insert Fig. 2 about here

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The mean values of P(FA) were 0.20 in the context condition and 0.09 in the no-context condition. A *t* test for repeated measures indicated that the false-alarm rate was significantly higher for the context than for the no-context condition, $t(7)=4.04$, $p<.01$.

For P(H), the main effects of signal type, $F(2,14)=48.37$, $p<.001$, and context, $F(1,7)=13.50$, $p<.01$, and the interaction between signal type and context, $F(2,14)=13.91$, $p<.001$, were significant. Simple effects were computed to examine the nature of the interaction further. The simple effects of context on the hit rate were significant for the constant signal, $F(1,7)=47.01$, $p<.001$, but neither for the rising, $F(1,7) < 1.0$, nor the falling, $F(1,7) < 1.0$, signal. As Figure 2 indicates, the hit rate for the constant signal was lower in the contextual than in the no-context condition; however, context had no effect on the hit rate for the rising or falling signals.

## Discussion

Auditory induction has been demonstrated in previous studies only with

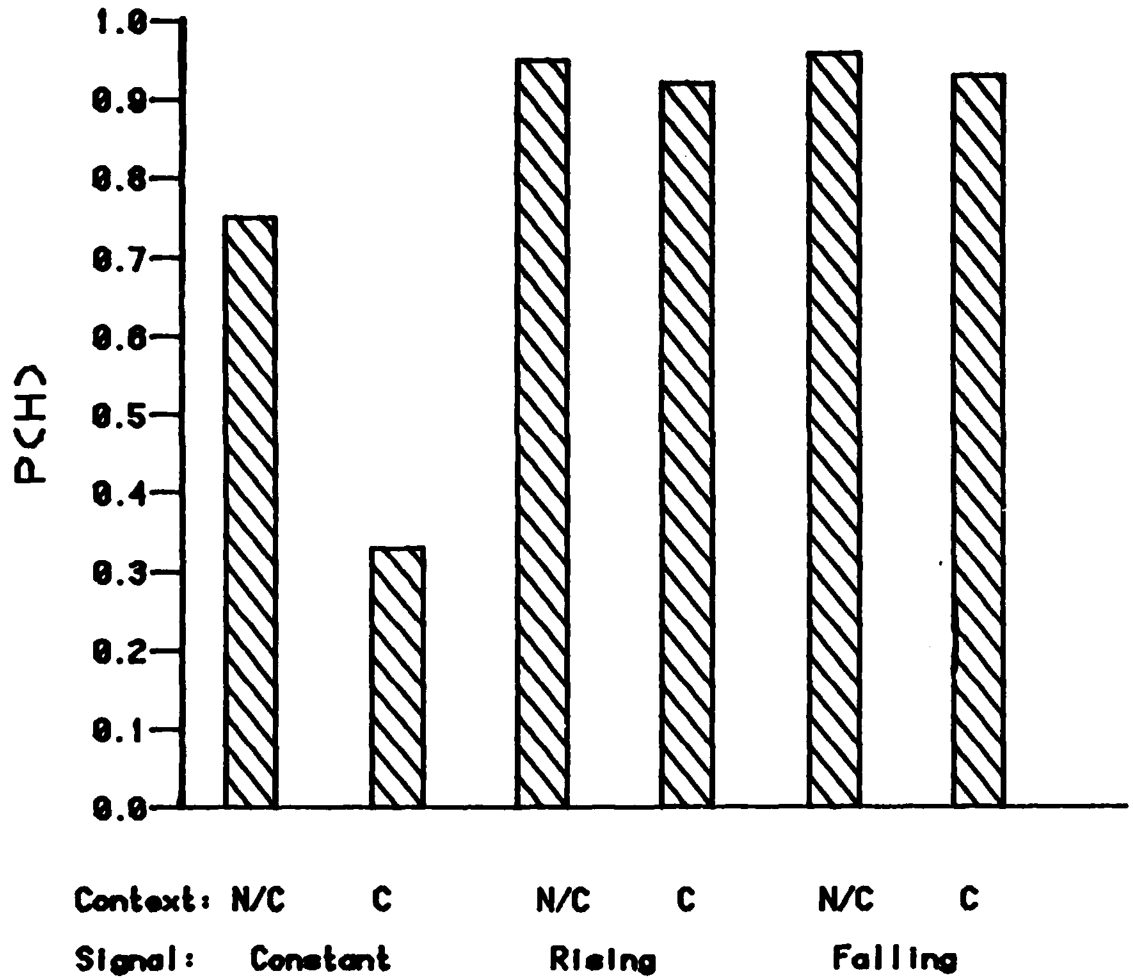


Figure 2. Mean values of the hit rate, P(H), for the three signal types, constant, rising, and falling, in the no-context and context conditions in Experiment 1.

continuous alternation of sounds (e.g., Miller & Licklider, 1950; Thurlow, 1957; Warren et al., 1972; Dannenbring, 1976) although Plomp (1981) briefly discussed the possibility of induction for discrete sounds. The results of the first experiment indicated that auditory induction effects can be obtained under discrete presentation conditions. With appropriate contextual tones a constant frequency signal can be induced, and is perceived as continuing through an intervening noise burst. The results of the first experiment also indicate that induction degrades perceptual performance. As a consequence, since listeners apparently "hear" (induce) the signal tone even when not present, there is a marked increase in the false-alarm rate. Induction affects performance only for signals that are presented "in-context" (a constant-frequency signal in a constant-frequency tone context) but not for signals that are "out-of-context" (rising or falling frequency signals). However, the increase in false-alarm rate across conditions, which suggests that induction leads to a more relaxed detection criterion, was not accompanied by a similar increase in hit rate, which decreased significantly for "in-context" signals. This suggests that the context condition also produced a decrease in sensitivity. However, this could not be tested since a pure measure of sensitivity (e.g., d' or P(A)) could not be computed separately for each context-signal combination.

An explanation of the decrease in hit rate in terms of masking is also possible, i.e., the contextual tones were a more efficient masker for the constant signal than for the rising or falling signals. To explore this possibility Experiment 2 attempted to minimize the effects of masking and change the predictions based on induction by including different contextual tone pairs. A small modification in the procedure was made. False alarms could not be partitioned by signal type in Experiment 1 since signal type was varied within

blocks. Thus the increase in false-alarm rate in the context condition could not be attributed to any one context-signal combination. To examine whether induction produces an increase in false alarms only for the associated context-signal combination, signal type was varied across blocks in Experiment 2. This procedure also allowed measures of sensitivity to be obtained separately for each context-signal combination.

## Experiment 2

The same signal parameters used in Experiment 1 were used in Experiment 2. However, two contextual conditions were compared: falling, or high-to-low (H-L) and rising, or low-to-high (L-H) frequency contexts. Figure 3 shows the composite structure of each contextual condition. If auditory induction were to occur the frequency transition (glide) would be perceived as continuing through the noise burst when the contextual tones were consistent with the signal. It was predicted therefore, that an interaction between contextual condition and signal would be obtained. A higher false-alarm rate and lower sensitivity would be obtained when the rising or falling signals were presented "in-context" (rising signal with L-H context; falling signal with H-L context) than when these signals are presented "out-of-context". Performance on the constant signal is predicted to be unaffected by context.

Insert Fig. 3 about here

### Method

Participants. Ten paid listeners aged 19-27 served as listeners in the experiment. All were recruited from a pool and none reported a history of

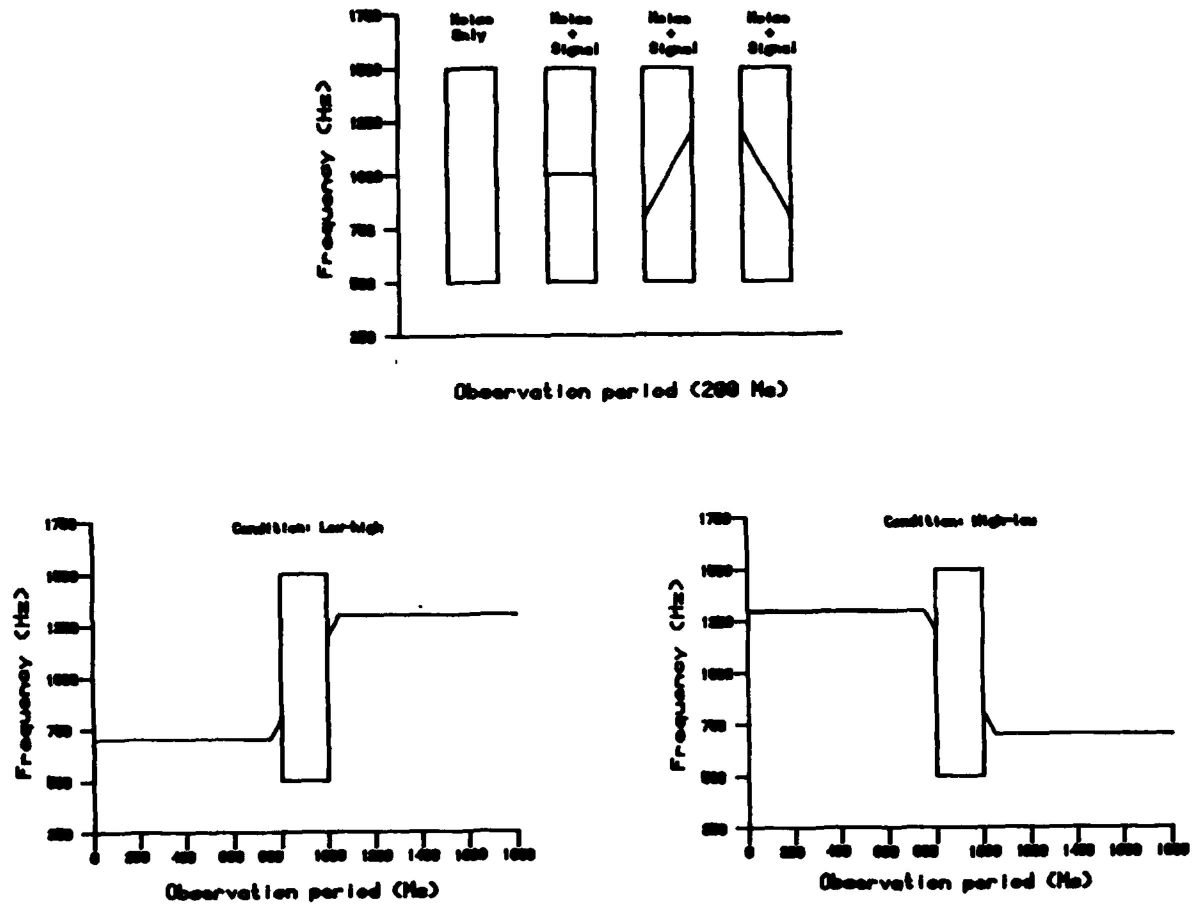


Figure 3. Composite structure of the stimuli in the yes-no detection task of Experiment 2. Constant, rising-, or falling-frequency signals were presented in a 200 ms noise burst (see upper half) that was preceded and followed by contextual tones. In the high-low (H-L) or falling context (lower right), the first segment of the contextual tone pair had a frequency of 1300 Hz and the second segment a frequency of 700 Hz. These values were reversed for the low-high (L-H) or rising context (lower left).

hearing disorder. None of the listeners had previous experience in psychoacoustic experiments. One listener was dropped due to an inability to detect signals with an E/No value of 19 at above-chance levels, and one listener was dropped midway through the first block due to equipment malfunction.

Stimuli. New 200 ms noise (N) and signal plus noise (SN) stimuli were constructed using the same parameters as in the previous experiment. The N and SN stimuli were preceded and then followed by 800 ms contextual tones. Two pairs of contextual tones were used: high-to-low (H-L) and low-to-high (L-H). The leading part of the H-L context pair began as a 750 ms pure tone of 1300 Hz and ended as a frequency glide which fell linearly from 1300 Hz to 1200 Hz in 50 ms. The trailing part of the H-L pair began as a 50 ms frequency glide which started at 800 Hz and fell linearly to 700 Hz and ended with a 750 ms pure tone of 700 Hz. The L-H context pair was constructed in a similar fashion (see Figure 3). All stimuli had 5 ms rise/fall times.

Apparatus. The apparatus was the same as that used in Experiment 1.

Procedure. Listeners were tested individually in two 1.5 hour sessions held on consecutive days. One practice block of 72 trials and six experimental blocks were given on each day. The practice block differed from that of Experiment 1 in that it contained two context conditions (H-L, L-H) instead of one, and a larger ratio of SN to N trials (.75 vs .50). The six experimental blocks given on each day were comprised of a factorial combination of the two (H-L, L-H) context conditions and the three signals, constant, rising, and falling. Each experimental block contained 96 trials, and therefore each context-signal combination was presented 192 times for an experiment-wide total of 1152 trials per listener. Short breaks were given between blocks and a long break was given after the third experimental block of each day.

## Results

The false-alarm rate, P(FA), and the hit rate, P(H), were computed as in Experiment 1, except that separate P(FA) values were obtained for each signal type. The hit and false-alarm probabilities were also used to compute a nonparametric estimate of sensitivity, P(A) (Pollack and Norman, 1964). Separate two (context condition) by three (signal type) analyses of variance were performed on the P(H), P(FA), and P(A) data.

Insert Fig. 4 about here

For P(FA) the effects of context, $F(1,7)=10.27$, $p<.025$, signal type, $F(2,14)=4.57$, $p<.05$, and the context by signal type interaction, $F(2,14)=12.35$, $p<.001$, were significant. A analysis of the simple effects indicated that the false-alarm rate for the falling signal was significantly higher in the H-L than in the L-H context condition , $F(1,14)=31.67$, $p<.001$, whereas the false-alarm rates for the rising, $F(1,14) < 1.0$, and constant, $F(1,14) < 1.0$, signals were not significantly different for context conditions. The P(FA) levels for context conditions are shown in Figure 4.

Insert Fig. 5 about here

For P(A) the context by signal-type interaction was significant, $F(2,14)=17.07$, $p<.01$, while the main effects of signal type, $F(2,14) < 1.0$, and context, $F(1,14) < 1.0$, were not significant. The simple effects of context on sensitivity were not significant for either the constant signal, $F(1,14) < 1.0$,

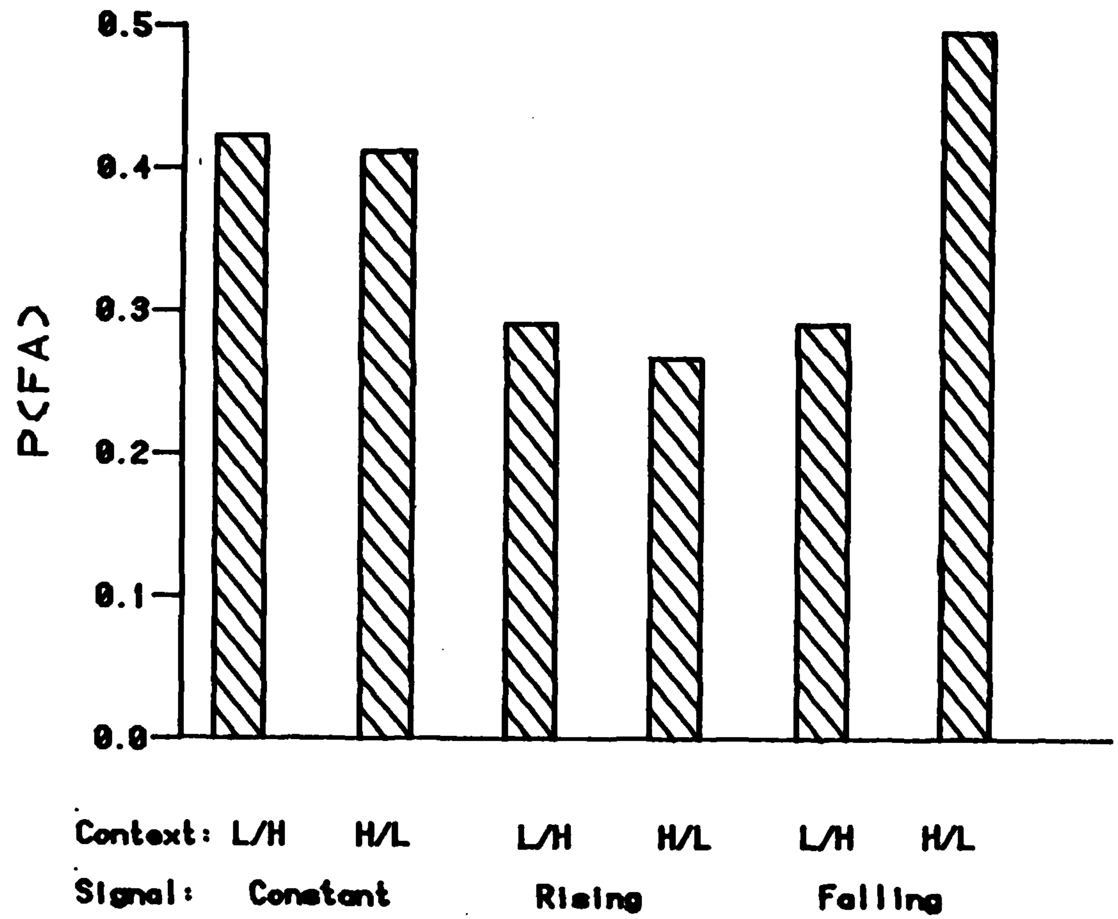


Figure 4. Mean values of the false-alarm rate, P(FA), for the three signal types, constant, rising, and falling, in the low-high and high-low context conditions in Experiment 2.

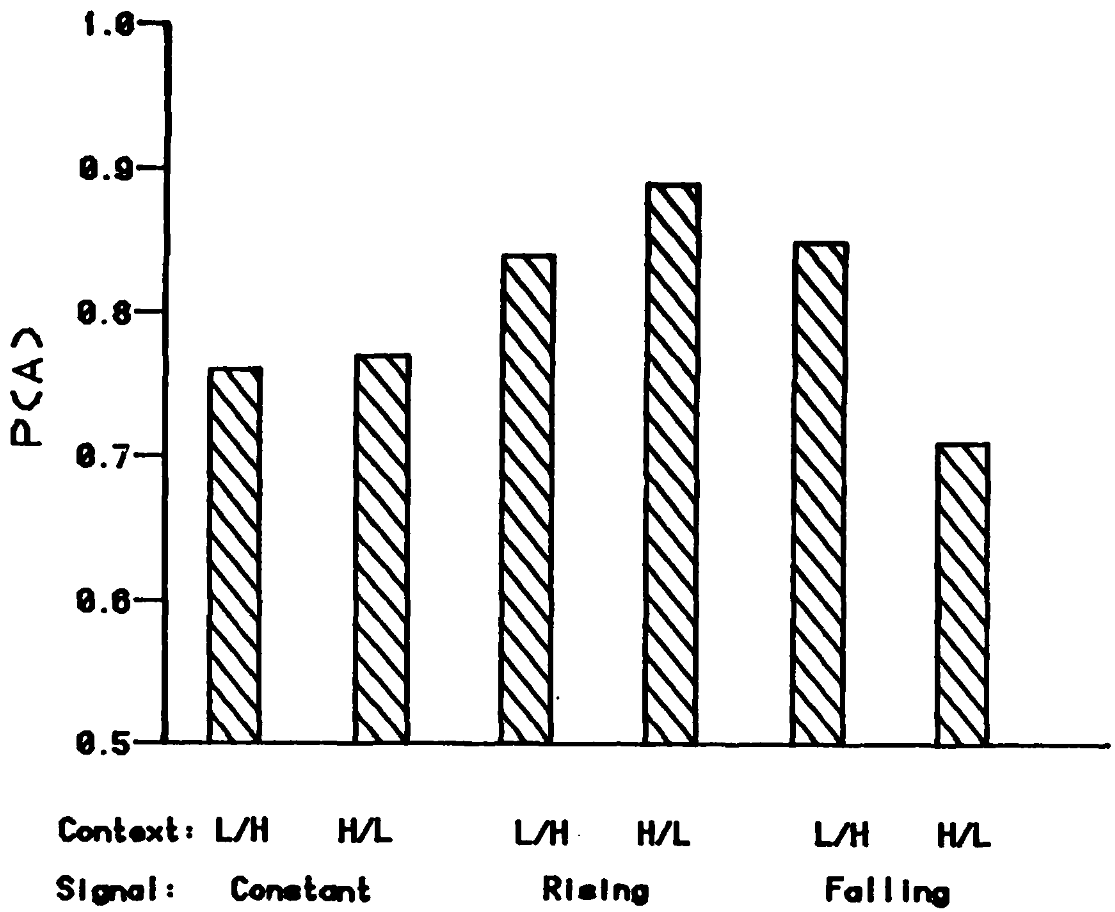


Figure 5. Mean values of sensitivity, P(A), for the three signal types, constant, rising, and falling, in the low-high and high-low context conditions in Experiment 2.

or the rising signal, $F(1,14)=3.97$, $p<.10$, but highly significant for the falling signal, $F(1,14)=31.11$, $p<.001$. As Figure 5 indicates, sensitivity for the falling signal was lower in the H-L than in the L-H context condition, whereas sensitivity for the rising signal was slightly lower in the L-H than in the H-L condition; sensitivity for the constant signal was unaffected by context.

Insert Fig. 6 about here

For P(H) the main effect of signal type, $F(2,14)=4.27$, $p<.05$, and the context by signal-type interaction, $F(2,14)=14.20$, $p<.001$, were significant. The simple effects of the context on the hit rate were significant for the rising, $F(1,14)=16.13$, $p<.005$, and falling, $F(1,14)=11.20$, $p<.005$, signals but not for the constant signal, $F(1,7) < 1.0$. As Figure 6 indicates, the hit rate for the rising signal was lower in the L-H than in the H-L contextual condition whereas the hit rate for the falling signal was lower in the H-L than in the L-H contextual condition.

Discussion

The results of Experiment 2 show that induction leads to a increase in false alarms that is specific to the associated context-signal combination. In addition, the results confirmed that sensitivity of the constant-frequency signal was unaffected by context, whereas sensitivity for the rising and falling signals were lowered when presented "in-context" (rising and falling contexts, respectively). Overall, the results of Experiment 2 complement those of Experiment 1 by showing that induction effects can be obtained for changing-frequency signals as well as for a constant-frequency signal.

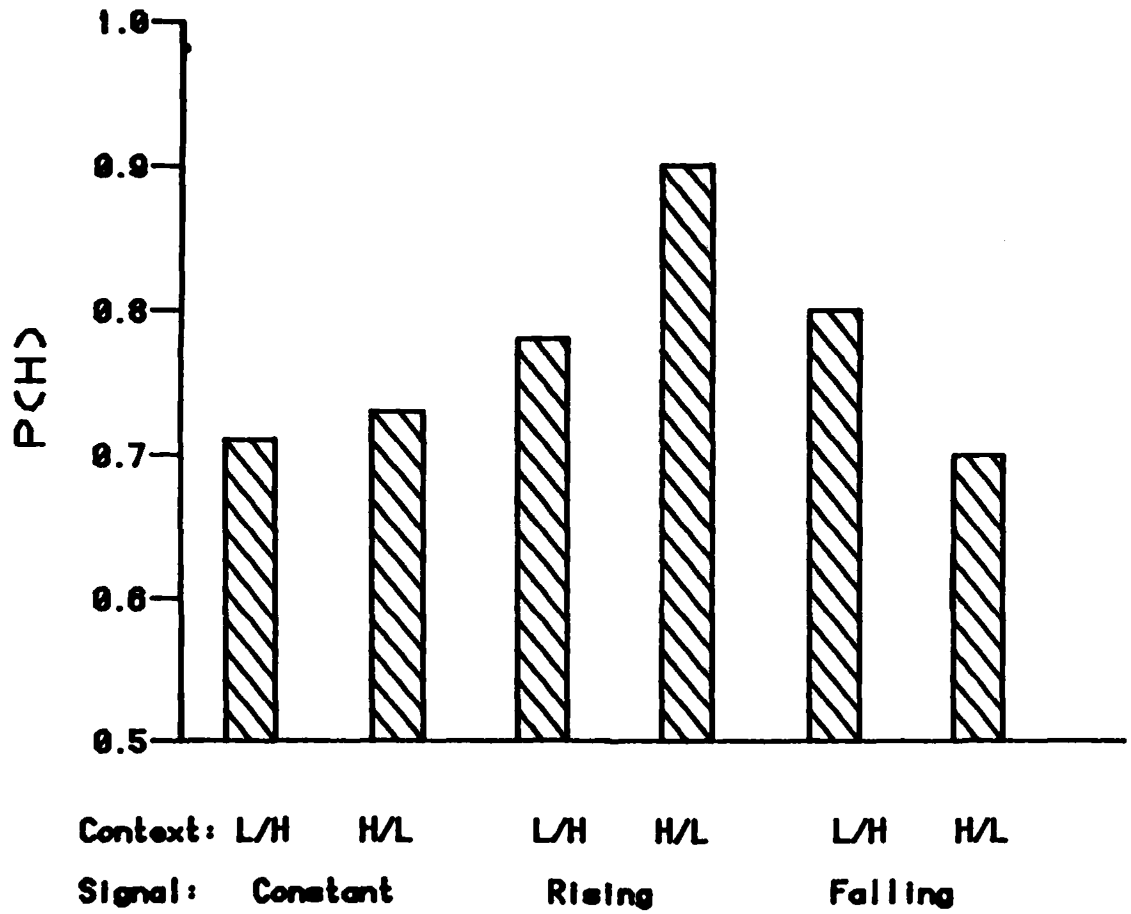


Figure 6. Mean values of the hit rate, P(H), for the three signal types, constant, rising, and falling, in the low-high and high-low context conditions in Experiment 2.

Although the role of peripheral masking is minimized (relative to Experiment 1) it is still possible to argue that the induction effects observed in Experiment 2 could be attributed to peripheral masking factors. The argument is similar to that discussed in Experiment 1, but more complicated. Performance on the in-context conditions might be lower due to differential masking by the contextual tones because, for example, with the L-H contextual pair any signal would be initially forward-masked by the low frequencies of the first contextual tone and subsequently backward-masked by the high frequencies of the second contextual tone. However, this masking would be more efficient for the rising signal than for the falling or constant signal. A similar argument could be put forward for the H-L contextual pair. To investigate whether differential peripheral masking could account for the induction effects obtained in Experiments 1 and 2, a third experiment was conducted in which the contextual tones and noise bursts were presented to different ears. It was predicted that when a signal and its context were consistent that an increase in false alarms and a lowering of sensitivity would be obtained.

## Experiment 3

Experiment 3 was similar to Experiment 2 except that the to-be-induced and inducing sounds were presented to different ears. Only two signals were used, the rising and falling-frequency tones. As in Experiment 2 it was hypothesized that a signal which was consistent with its contextual tones would yield a higher false-alarm rate as well as lower sensitivity than for the same signal presented in an inconsistent context. If the induction effects obtained in Experiments 1 and 2 were due to peripheral masking then no context effects should be observed.

## Method

Participants. Eleven paid listeners aged 19-31 served as listeners in the experiment. All were recruited from a pool and none reported a history of hearing disorder. Six listeners had previous experience in psychoacoustic experiments. Three listeners were dropped after one session because they were unable to detect tones with a signal-to-noise ratio of E/No=17 at above-chance levels.

Stimuli. New 200 ms N and SN stimuli were constructed using the same parameters as in the previous experiments except that the SN bursts had a lower signal-to-noise ratio (E/No of 17), and the constant signal was not included in the experiment. The contextual tones were exactly the same as Experiment 2.

Apparatus. Another channel using similar instrumentation was employed to enable sound presentation to different ears. The contextual tones were played over the second output channel of the d-a converter, attenuated (Texscan, model SA-50), low-pass filtered at 2.5 khz (Krohn-Hite, model 3550), and presented over matched, calibrated Telephonics headphones (model TDH-50P). All other instrumentation was exactly the same as in the previous experiments.

Procedure. Listeners were tested individually in two 1-hour sessions held on consecutive days. One practice block of 54 trials and four experimental blocks of 96 trials were given on each day. The practice block differed from that of the previous experiments in several ways. First, the ratio of SN to N trials was different (.66 vs .50 and 75). Second, both the first and second experiments had practice stimuli with and without contextual tones. Experiment 3 only had stimuli with contextual tones. Finally, the signal-to-noise ratio of the stimuli was lower than in the previous experiments: the initial level (E/No=21) was reduced to E/No= 19, and to E/No=17, the level used in the

experimental blocks.

The four experimental blocks were comprised of a factorial combination of the two (H-L, L-H) context conditions and the two signal types (rising and falling). Experimental blocks were presented in a randomized order and with only one signal type and one context in a block. In a given trial an N or SN stimuli could occur with equal probability. Each experimental block contained 96 trials, and therefore each context-signal block contained 192 trials for an overall total of 768 experimental trials per listener. Listeners were instructed to reverse the headphones after a practice or experimental block; short breaks were given after each block except the second experimental block where listeners were instructed to take a longer break.

## Results

The false-alarm rate, P(FA), the sensitivity index, P(A) and the hit rate, P(H), were computed as in Experiment 2. Table 1 shows the mean values of each of these measures averaged over the eight listeners. A two (context condition) by two (signal type) analysis of variance was performed on the P(FA), P(A), and P(H), data.

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Insert Table 1 about here

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For P(FA) the context by signal interaction was significant, $F(1,7)= 9.93$, $p<.025$. An analysis of the simple effects indicated that the false-alarm rate for the rising tone was significantly higher in the L-H context condition than the H-L context condition, $F(1,7)= 9.55$, $p<.025$. Although the change in the false-alarm rate for the falling signal across context conditions was in the

Table 1

Mean Values of the False-Alarm Rate, P(FA), Sensitivity, P(A), and Hit Rate, P(H), for the Two Signal Types, Rising and Falling, for the Low-High (L-H) and High-Low (H-L) Context Conditions in Experiment 3.

| | Observation conditions | | | |
|---|---|---|---|---|
| | Rising | | Falling | |
| Measures: | L-H | H-L | L-H | H-L |
| P(FA) | .30 | .17 | .22 | .28 |
| P(A) | .76 | .86 | .87 | .79 |
| P(H) | .67 | .86 | .83 | .77 |

predicted direction (higher in the L-H than in the H-L condition), the change was not significant.

The mean values of sensitivity are shown in Table 1. For P(A) the signal by context interaction was significant, $F(1,7)=8.30$, $p<.025$. An analysis of the simple effects of context on sensitivity was not significant for either the rising signal, $F(1,7)= 4.42$, $p<.10$, or the falling signal, $F(1,7)=2.83$, $p<.20$.

For P(H) the context by signal type interaction, $F(1,7)=7.78$, $p<.05$, was significant. The simple effects of the context on the hit rate were significant for the rising signal, $F(1,7)=9.35$, $p<.025$, but not for the falling signal, $F(1,7)<1.0$. As Table 1 indicates the hit rate for the rising tone was lower in the L-H contextual condition. The mean hit-rate for the falling tone was lower in the H-L contextual condition, but not significantly so.

Discussion

The results of Experiment 3 are similar to those of Experiment 2. The false-alarm rate was higher and the sensitivity and detection rate were lower for the rising signal when presented in the L-H context than when presented in the H-L context. The opposite was true for the falling signal, although the simple effects of context, while in the predicted direction, were not significant.

In general, the results of Experiment 3 indicate that auditory induction cannot be attributed solely to peripheral-masking factors. Since the to-be-induced and inducing sounds were presented to different ears, effects of either forward or backward peripheral-masking of the signals by the contextual tones were eliminated. Nevertheless, the same pattern of selective context-signal sensitivity impairment observed in Experiments 1 and 2 was obtained.

General discussion

The results indicate that auditory induction is a general phenomenon that can influence the perception of nonspeech sounds which are either constant or changing in frequency. By varying the type of signal and the contextual tone, it was shown that performance is lowered only for signals that are "in context." That is, the false-alarm rate in detecting a pure-tone signal embedded in a noise burst is increased and sensitivity lowered if the signal is preceded and followed by a tone which provides a "context" consistent with the signal. For example, detection of a constant-frequency signal is impaired in the context created by constant-frequency tones, but not in contexts created by rising or falling-frequency tones. Detection of a rising-frequency signal, on the other hand, is significantly poorer in a rising-tone context compared to a constant or falling-tone context. The contextual tone appears to continue through the noise burst and the consequence of auditory induction is an impairment in the detection of the signal.

The generalizability of previous research on auditory induction is limited since rapid alternation has been shown to distort the perception of stimuli (Bregman, 1978). In these studies listeners were presented with alternating sounds and were asked to adjust the duration or intensity of one of these alternating sounds until induction occurred. Houtgast (1972, p. 1891) states that "the existence of such a pulsation threshold is a very general feature of alternating stimuli." The present study demonstrates that auditory induction is a general feature of non-alternating or discrete stimuli as well.

The use of discrete rather than non-alternating stimuli also allows a signal-detection paradigm to be employed in the study of auditory induction. As Samuel (1981a, 1981b) has demonstrated in a study of phonemic restoration, this

method allows the effects of auditory induction on perceptual performance to be evaluated. Samuel (1981a) showed that auditory induction can be beneficial to the perception of speech. The present study indicates, however, that auditory induction may not always be beneficial. In the perception of nonspeech sounds, auditory induction may also degrade performance by "restoring" sounds not present in that part of the auditory input being monitored, thus leading to an increase in false-signal reports. Thus although induction may be beneficial to perception, it can also degrade perceptual performance. In the present study factors other than auditory induction may have degraded performance. In particular it may be argued that the effects attributed to auditory induction result from both peripheral and central masking.

Role of peripheral masking in auditory induction

It is possible that peripheral factors, notably masking, could have affected the results obtained in this study. In Experiment 1 detection of the constant-frequency tone was significantly impaired by the presence of a constant-frequency context (compared to detection with no context) while detection for the other signals remained relatively unchanged. An interpretation based on auditory induction would maintain that the tone was perceived as continuing through the noise and that this illusion impaired detection performance. However, the overall detectability of the constant-frequency signal was lower than that of the rising or falling signals. This suggests that the in-context impairment in the detectability of the constant signal could be due both to induction and to peripheral masking: since the constant signal and the contextual tones were the same frequency, backward and forward masking due to the contextual tone would be more efficient for the constant signal than for the other signals.

Overall detection performance was also lower for the constant signal than for the rising or falling signal in Experiment 2. However, unlike Experiment 1, sensitivity for the constant tone did not differ between the rising and falling constant-frequency contexts while sensitivity for the rising and falling signals did vary with context. Thus, induction differentially impaired signal-detection performance, but the results do not rule out the possibility that peripheral masking also had an effect. In fact, Evans (1973) has argued that induction is only some combination of backward and forward masking.

This argument could be applied to the results of the second experiment as well. As an example consider the H-L contextual-tone pair. It was shown that a higher hit-rate and a lower false-alarm rate were obtained for the rising signal than for the other signals. It could be argued that the first context tone provided a more efficient forward-masker for the initial portion of the falling and constant signals than for the rising signal. Similarly, the lower frequencies of the second contextual-tone would be a more efficient backward-masker for the falling and constant signals than for the rising signal.

Consideration of the critical band for pure-tone maskers does not support this conclusion. Estimates of the critical-band width suggest that although the contextual tones were closer in frequency range to the in-context signal than out-of-context signals, they may not have been sufficiently close to account for the pattern of results obtained. Consider the rising signal in the L-H context in Experiment 2. The L-H context consisted of a 700 Hz and 1300 Hz pair (see Figure 3). The rising signal rose in frequency from 700 Hz to 1300 Hz. The constant signal had a frequency of 1000 Hz and the falling signal had a frequency that fell from 1300 Hz to 700 Hz. Thus, although the starting and ending portions of the rising signal would be more effectively forward and

backward-masked by the contextual tones than either the constant or falling signals, a substantial portion of the energy in the middle portion of the rising signal (from 900 Hz to 1100 Hz) would lie outside the effective masking region of the contextual tones. If one assumes, conservatively, an average masking band of about 100 Hz, the energy of the rising signal would lie outside the masked-frequency region for about half the duration of the signal. It seems improbable that the consistent pattern of results obtained in the first two experiments could be solely attributed to peripheral masking.

<u>Role of central masking in auditory induction</u>

There are two sources of masking which could be responsible for induction effects: central and peripheral, and thus the results could still be attributed to central masking. Experiment 3 attempted to rule out peripheral masking as an explanation of auditory induction by presenting the contextual tones (inducing sounds) to one ear and the N and SN bursts (containing to-be-induced sounds) to the other ear. A pilot study indicated that the signal-to-noise ratio used in the previous studies resulted in almost perfect performance and therefore the ratio was lowered. The same pattern of results that are predicted by induction and demonstrated in the previous studies was obtained when the contextual tones and noise bursts were presented to separate ears.

The results of Experiment 3 indicate that an explanation of auditory induction solely on the basis of masking is improbable. The most parsimonious explanation of the results of Experiments 2 and 3, therefore, is as follows. The contextual tones that precede and follow the signal to be detected do produce masking which degrades performance, but this degradation is general in nature, and has the effect of lowering overall detection-performance for all signal types (as evidenced by the necessity of lowering the S/N ratio in

Experiment 3). The contextual tones also produce auditory induction, but the effects of induction are not general but specific to signal type--detection is impaired only for "in-context" signals. The possibility of a central masking mechanism still exists, but it seems unlikely central masking alone could produce the differential results obtained. This would indicate that auditory induction is a "true effect," independent of masking, and one that is mediated centrally.

Summary

In conclusion, these results indicate that auditory induction is a general factor influencing auditory perception and can be demonstrated either for discrete as well as continuous presentation of sounds. While induction of "missing" sounds can be beneficial, especially in speech perception, auditory induction can also impair perceptual performance, particularly in monitoring nonspeech sounds for faint signals. Finally, auditory-induction effects can be distinguished from peripheral-masking effects, and although a relation between auditory induction and central masking cannot be ruled out, induction and masking appear to be separate, independent factors, one largely central, the other largely peripheral in nature.

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## Acknowledgements

This research was supported by a contract from the Engineering Psychology Group of the Office of Naval Research to the third author. The authors thank John J. O'Hare for his comments on an earlier version of the manuscript. Requests for reprints should be addressed to Kevin B. Bennett, Human Performance Laboratory, The Catholic University of America, Washington, D. C., 20064.

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